ANNEX J: Methodology for Estimating Methane Emissions from Landfills

Landfill methane is produced from a complex process of waste decomposition and subsequent fermentation under anaerobic conditions. The amount and rate of methane production depends upon the characteristics of the landfilled material and the surrounding environment. To estimate the amount of methane produced in a landfill in a given year, the following information is needed: the quantity of waste in the landfill, the waste characteristics, the residence time of the waste in the landfill, and the landfill capacity.

The amount of methane emitted from a landfill is less than the amount produced in a landfill. If no measures are taken to extract the methane, a portion of itwill oxidize as it travels through the top layer of the landfill cover. The portion of the methane that oxidizes turns primarily to carbon dioxide (CO_2). If the methane is extracted and combusted (e.g., flared or used for energy), then that portion of the methane produced in the landfill will not be emitted as methane, but again, would be converted to CO_2. In general, CO_2 emissions are of biogenic origin and primarily result from the decomposition, either aerobic or anaerobic, of organic matter such as food or yard wastes.[1]

Methane emissions are driven by the quantity of waste in landfills over time. From an analysis of the population of municipal solid waste (MSW) landfills, landfill-specific data are extracted and used in an emissions model to estimate the amount of methane produced by municipal solid waste. Although not explicitly modeled, methane emissions from industrial landfills are assumed to be seven percent of the total methane generated from MSW at landfills. Total methane emissions are estimated by adding the methane from MSW landfills, subtracting the amount recovered or used for energy or flared, subtracting the amount oxidized in the soil, and adding emissions from industrial landfills. The steps taken to estimate emissions from U.S. landfills for the years 1990 through 1998 are discussed in greater detail below.

Step 1: Estimate Municipal Solid Waste-in-Place Contributing to Methane Emissions

First, landfills were characterized as of 1990 based on EPA's landfill survey (EPA 1988). Each landfill was characterized in terms of its year of opening, waste acceptance during operation, year of closure, and design capacity. Following characterization of the landfill population, waste was simulated to be placed in these landfills. For 1991 through 1998, waste disposal estimates were based on annual *BioCycle* (1999) data. Landfills were simulated to open and close based on waste disposal rates. If landfills reached their design capacity, they were simulated to close. New landfills were simulated to open when a significant shortfall in disposal capacity was predicted. Simulated new landfills were assumed to be larger, on average, reflecting the trend toward fewer and more centralized facilities. The analysis updated the landfill characteristics each year, calculating the total waste-in-place and the profile of waste disposal over time. Table J- 1 shows the amount of waste landfilled each year and the total estimated waste-in-place contributing to methane emissions.

Step 2: Estimate Landfill Methane Production

Emissions for each landfill were estimated by applying the emissions model (EPA 1993) to the landfill waste-in-place contributing to methane production. Total emissions were then calculated as the sum of emissions from all landfills.

Step 3: Estimate Industrial Landfill Methane Production

Industrial landfills receive waste from factories, processing plants, and other manufacturing activities. Because no data were available on methane generation at industrial landfills, emissions from industrial landfills were assumed to

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[1] Emissions and sinks of biogenic carbon are accounted for in the Land-Use Change and Forestry chapter.

equal seven percent of the total methane emitted from MSW landfills (EPA 1993). These emissions are shown in Table J-2.

Step 4: Estimate Methane Emissions Avoided

The quantity of methane flared – without a landfill gas-to-energy (LFGTE) system— was based on data collected from flaring equipment vendors. These data included information on the quantity of flares, landfill gas flow rates, and year of flare installation. Total methane recovered was estimated by multiplying the number of flares by a landfill gas flow rate provided by a flaring equipment vendor.

The quantity of methane avoided due to LFGTE systems was estimated based on the data included in a database compiled by EPA's Landfill Methane Outreach Program (LMOP). Using data on landfill gas flow and energy generation, the total direct methane emissions avoided were estimated.

Step 5: Estimate Methane Oxidation

As discussed above, a portion of the methane escaping from a landfill through its cover oxidizes in the top layer of the soil. The amount of oxidation that occurs is uncertain and depends upon the characteristics of the soil and the environment. For purposes of this analysis, it was assumed that ten percent of the methane produced, minus the amount of gas recovered for flaring or LFGTE projects, was oxidized in the soil (Liptay et al. 1998).

Step 6: Estimate Total Methane Emissions

Total methane emissions were calculated by adding emissions from MSW and industrial waste, and subtracting methane recovered and oxidized, as shown in Table J-2.

Table J- 1: Municipal Solid Waste (MSW) Contributing to Methane Emissions (Tg)

Description	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Total MSW Generated[a]	267	255	265	279	293	297	297	309	340
Percent of MSW Landfilled[a]	77%	76%	72%	71%	67%	63%	62%	61%	61%
Total MSW Landfilled	206	194	191	198	196	187	184	189	207
MSW Contributing to Emissions[b]	4,926	5,027	5,162	5,292	5,428	5,560	5,677	5,791	5,907

MMT = million metric tons

[a] Source: *BioCycle* (1999). The data, originally reported in short tons, are converted to metric tons.

[b] The EPA emissions model (EPA 1993) defines all waste that has been in place for less than 30 years as contributing to methane emissions.

Table J-2: Methane Emissions from Landfills (Gg)

Activity	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
MSW Generation	**11,599**	**11,837**	**12,168**	**12,499**	**12,848**	**13,220**	**13,492**	**13,776**	**14,017**
Large Landfills	4,534	4,625	4,767	4,918	5,115	5,298	5,464	5,641	5,811
Medium Landfills	5,791	5,912	6,070	6,222	6,348	6,514	6,605	6,697	6,752
Small Landfills	1,273	1,300	1,332	1,359	1,385	1,407	1,423	1,438	1,453
Industrial Generation	**731**	**746**	**767**	**787**	**809**	**833**	**850**	**868**	**883**
Potential Emissions	**12,330**	**12,582**	**12,935**	**13,287**	**13,658**	**14,052**	**14,342**	**14,644**	**14,900**
Emissions Avoided									
Landfill Gas-to-Energy	(811)	(861)	(915)	(1,053)	(1,183)	(1,233)	(1,397)	(1,608)	(2,025)
Flare	(299)	(524)	(637)	(764)	(952)	(1,171)	(1,363)	(1,454)	(1,564)
Oxidation	(1,049)	(1,045)	(1,062)	(1,068)	(1,071)	(1,081)	(1,073)	(1,071)	(1,043)
Net Emissions	**10,171**	**10,152**	**10,321**	**10,402**	**10,452**	**10,566**	**10,508**	**10,510**	**10,268**

Note: Totals may not sum due to independent rounding.

Table J-3: Municipal Solid Waste Landfill Size Definitions (Gg)

Description	Waste-in-Place
Small Landfills	< 400
Medium Landfills	400 – 2,000
Large Landfills	> 2,000